Chapter 9
Dual-Phase Extraction (Bioslurping)

9-1. General

The processes of dual-phase extraction and bioslurping are described in the chapter's first section. The second portion of the chapter is a hazard analysis with controls and control points listed.

9-2. Technology Description

Water immiscible contaminants (hydrophobic), such as many hydrocarbons and chlorinated hydrocarbons, can sink through the soil pore spaces to groundwater. When less dense than groundwater, the materials float in a spreading layer, depressing the groundwater surface tension slightly. Typical recovery is by a down-hole pump in a well. Material recovered is a mixture of hydrocarbons and groundwater.

a. Dual-Phase Extraction.

Dual-phase extraction modifies the typical design for well construction and recovery methods for groundwater non-aqueous phase liquids (NAPL) by the insertion of a vacuum extraction pipe ("straw") down the well casing bore to the water table surface. The wellhead is sealed, and the extraction pipe is connected to a vacuum pump (capable of drawing a relatively high vacuum, more than 0.5 atm) at the surface. The pump draws a mixture of air, water, and NAPL from the water surface by aspirating the liquid into the soil gas stream. The mixture of air, water, and NAPL is low in average density, which allows this extraction technique to be used at depths greater than an atmosphere pressure of water head. The two (or three) phases are separated on the surface in a series of separators, first liquid/vapor and then oil/water separators if needed. The soil gas replenishment is from the surrounding formation and eventually the surface so the process effectively aerates the vadose zone around the well. This can be used for biological enhancement, leading to the term "bioslurping." The process is illustrated in Figure 9-1.

b. Bioslurping.

The aeration of the vadose zone around the well can be used for biological enhancement or *bioslurping.* The three-phase flow (the combination of air and water flow above and below the NAPL) assists in pulling the NAPL into the well bore at a rate often exceeding conventional liquid pumping methods. The method may permit more effective dewatering of very tight soil formations. The method is applicable to NAPL sites and vadose zone contamination by volatile organic carbon compounds (VOCs) and degradable semi-volatile organic compounds (SVOCs). In bioslurping, the process is operated as described above, except the air and water movement are exploited to promote in-situ bioremediation during free-product recovery. This is occasionally done by reinjecting and reinfiltrating the recovered groundwater but with oxygen and nutrients added. This, in combination with the movement of unsaturated zone air, provides bioventing and closed loop in-situ bioremediation of the groundwater. Thus,

bioslurping is a combination of free-product recovery, bioventing, and in-situ bioremediation.

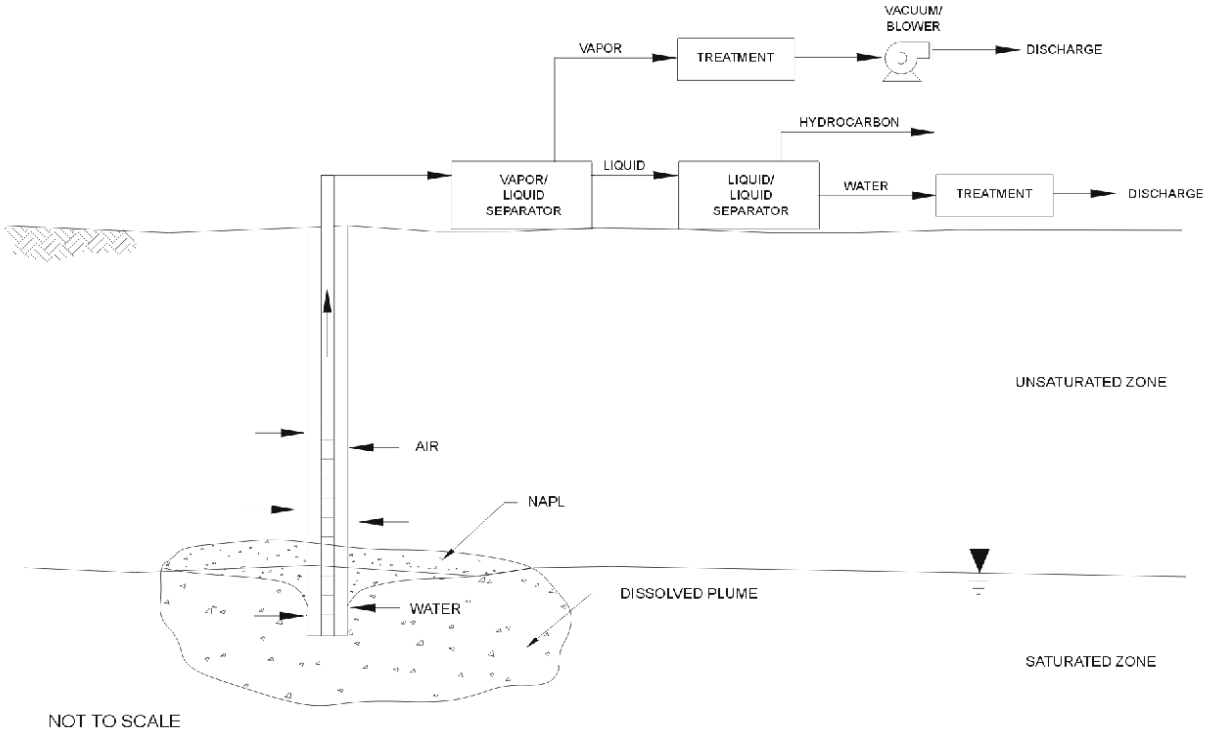

FIGURE 9-1. DUAL-PHASE EXTRACTION/BIOSLURPING

9-3. Hazard Analysis

Principal unique hazards associated with dual-phase extraction (bioslurping), methods for control, and control points are described below.

a. Physical Hazards.

(1) *Fire and Explosion Hazards (Drilling).*
Description. Soil boring using hollow-stemmed augers may cause a fire or explosion during drilling into soils saturated with flammable or combustible materials in unusual or extraordinary conditions. Sparks generated when a metal auger strikes against rocks, metal, or other underground objects may ignite a flammable atmosphere inside the borehole.

Control. A control for fire/explosion includes:

- Train operators in the hazards of drilling into or through flammable liquids or materials.

- Train operators in emergency procedures in case of a catastrophic event, in life saving first aid procedures including extinguishing flames, extracting, extinguishing and stabilizing victims, and in emergency drill system isolation and shutdown procedures.
- Use methods such as mud or water rotary drilling, which add moisture to the cutting area.

CONTROL POINT: Design, Construction

(2) *Utility Contact Hazard.*
Description. Fire, explosion, or electrocution hazards may exist during hollow-stemmed auger drilling if the rotating auger contacts and ruptures underground utilities, such as electrical or gas lines, or comes in contact with overhead electric lines.

Control. Controls for utility contact hazards include:
- Train operators in the hazards of drilling in the vicinity of underground or overhead utilities.
- Train operators in emergency procedures in case of a catastrophic event, in life saving first aid procedures for electrocutions, burns, and extinguishing flames, extracting, extinguishing and stabilizing victims, and in emergency drill system isolation and shutdown procedures.
- Contact local utilities and public works authorities to determine the locations of all utilities. When there is any doubt or uncertainty, perform a utility survey, probe with a metal rod, or hand excavate to determine the exact location of utilities prior to drilling. Once utilities are located, careful excavation by backhoe may be allowed.
- Post an observer to the side to guide when raising a drill mast.
- Do not move the drilling rig with the mast raised.

CONTROL POINT: Design, Construction

(3) *Fire and Explosion Hazards (Transfer of Flammable Gas/Liquids).*
Description. During the transfer of extracted flammable or combustible liquids (such as jet fuel) and gas from the recovery wells, a fire or explosion hazard may exist. The liquid or gas may be ignited by equipment or from the discharge of static electricity.

Control. Controls for fire and explosion hazards include:
- Train the operators in the hazards of the collection system including the reactivity of the contaminants extracted, and the sources of ignition including static electricity.
- Train the operators in emergency procedures in case of a catastrophic event, in life saving first aid procedures including extinguishing flames, extracting, extinguishing and stabilizing victims, and in emergency recovery system isolation and shutdown procedures.

- Verify that the hazardous area classifications, as defined in NFPA 70, Chapter 5, sections 500.1 through 500.10, are indicated on the drawings.
- Perform all electrical work according to code and under the supervision of a state licensed master electrician.
- Use all controls, wiring, and equipment in conformance with the requirements of EM 385-1-1, Section 11, and NFPA 70 for the identified hazard areas.
- Check for appropriate design and installation of equipment.
- Use grounded equipment or equipment provided with ground fault circuit interrupter (GFCI) protection if required by EM 385-1-1, Section 11, or NFPA 70 requirements.

CONTROL POINT: Design, Construction, Maintenance

(4) *Fire and Explosion Hazards (Recovery Tank).*
Description. If the product recovered by the technology is a flammable or combustible liquid (such as jet fuel), a fire or explosion hazard may exist with the product recovery tank.

Control. A control for fire or explosion in the recovery tank includes:

- Train the operators in the hazards of the collection system, including the reactivity of the contaminants extracted, and the sources of ignition, including static electricity.
- Train the operators in emergency procedures in case of a catastrophic event, in life saving first aid procedures including extinguishing flames, extracting, extinguishing and stabilizing victims, and in emergency recovery system isolation and shutdown procedures.
- Use controls, wiring, and equipment in conformance with the requirements of EM 385-1-1, Section 11, and NFPA 70 for the identified hazard.

CONTROL POINT: Design, Construction, Maintenance

(5) *Fire and Explosion Hazards (Emissions/Flammable Vapors).*
Description. Emissions from collection equipment may be ignited, possibly causing a fire or explosion. In addition, ejector pumping systems produce mixtures of flammable vapors and air that may be ignited and result in an explosion.

Control. Controls for fire or explosion due to emissions include:

- Train the operators in the hazards of the collection system, including the reactivity of the contaminants extracted, and the sources of ignition, including static electricity.
- Train the operators in emergency procedures in case of a catastrophic event, in life saving first aid procedures including extinguishing flames, extracting, extinguishing and stabilizing victims, and in emergency recovery system isolation and shutdown procedures.
- Perform regular inspections of the collection equipment to identify and repair system leaks.

- Do not use piping systems and ejectors that mix air with flammable vapors.

CONTROL POINT: Design, Operations, Maintenance

(6) *Equipment Hazards (Drilling).*
Description. Loose clothing may become entangled in cables used to raise and lower drilling tools and equipment or on other equipment. Direct push drilling methods using hydraulic pressure to advance a soil boring may pose a crushing hazard to hands or feet.

Control. Controls for equipment hazards from drilling include:
- Use cable systems with caution and inspect regularly for loose strands or frayed wires that may entangle loose clothing.
- Prohibit the wearing of loose fitting clothing.
- Keep hands and feet away from hydraulic push equipment.

CONTROL POINT: Construction, Operations, Maintenance

(7) *Rotating Equipment.*
Description. The rotating auger of a drill rig poses a hazard to workers as loose clothing may become entangled with the revolving auger.

Control. Controls for rotating equipment include:
- Prohibit the use of loose clothing.
- Use low-profile auger pins.
- Use long-handled shovels to remove soil cuttings from the borehole.

CONTROL POINT: Construction, Maintenance

(8) *Fire or Explosion (Containment Tank).*
Description. Containment tanks used for storage of recovered free product may overflow, creating the potential for fire or explosion.

Control. Controls for fire/explosion attributable to containment tanks include:
- Train the operators in the hazards of the collection containment system, including the reactivity of the contaminants extracted, and the sources of ignition, including static electricity.
- Train the operators in emergency procedures in case of a catastrophic event, in life saving first aid procedures including extinguishing flames, extracting, extinguishing and stabilizing victims, and in emergency recovery system isolation and shutdown procedures.
- Use NFPA-approved fluid level indicators appropriate for the fuels encountered.
- Install indicators on free-product recovery tanks to help prevent overflowing.
- Conduct regularly scheduled tank inspections.

CONTROL POINT: Design, Operations, Maintenance

(9) *Fire Hazard (Piping Systems).*
Description. Piping systems that become plugged may induce failure of the vacuum pump, causing an electrical fire.

Control. Controls for fire attributable to piping systems include:

- Train the operators in the hazards unique to the piping system, including the reactivity of the contaminants, and the sources of ignition including electrical fires.
- Train the operators in emergency procedures in case of a catastrophic failure of the piping system, in life saving first aid procedures including extinguishing flames, shutting down electrical power, extracting, extinguishing and stabilizing victims, and in emergency piping system isolation and shutdown procedures.
- Inspect and clean piping systems periodically to help prevent buildup of material that may cause blockage.

CONTROL POINT: Design, Operations, Maintenance

(10) *Heat Stress.*
Description. Workers may be exposed to elevated temperatures from hot blowers and other process equipment. The exposure may induce heat stress.

Control. Controls for heat stress include:

- Use the correctly sized blowers, motors, and other equipment to prevent overheating.
- Vigorously train workers in recognizing heat stress symptoms and prevention. Use the Buddy System of observation for symptoms.
- Provide plain cool water for body fluid replacement and require frequent replenishment, breaks, and shaded break areas.
- Monitor for heat stress using the physiological or Wet Bulb Globe Temperature (WBGT) Index protocol provided in the most recent publication of the American Conference of Governmental Industrial Hygienists (ACGIH) "TLVs and BEIs: Threshold Limit Values for Chemical Substances and Physical Agents & Biological Exposure Indices."

CONTROL POINT: Design, Maintenance

(11) *Explosion (Separators).*
Description. Separators that generate flammable vapors may explode if ignited.

Control. Controls for explosion due to separators include:

- Train operators in the hazards unique to the separators, including the reactivity of the contaminants, and the sources of ignition, including static electricity.

- Train operators in emergency procedures in case of a catastrophic failure of the piping system, in life saving first aid procedures including extinguishing flames or neutralizing chemical reactions, shutting down electrical power, extracting, extinguishing and stabilizing victims, and in emergency piping system isolation and shutdown procedures.
- Verify that the hazardous area classifications, as defined in NFPA 70 Chapter 5, sections 500.1 through 500.10, are indicated on the drawings.
- Use controls, wiring, and equipment in conformance with the requirements of EM 385-1-1, Section 11, and NFPA 70 for the identified hazard areas.
- Use grounded equipment or equipment provided with ground fault circuit interrupter (GFCI) protection if required by EM 385-1-1, Section 11, or NFPA 70 requirements.
- Permit only trained, experienced personnel to work on the systems.
- Ventilate areas adequately to help prevent the accumulation of flammable gases.
- Include appropriate lock-out/tag-out equipment and procedures in the O&M of the system.
- Provide fire extinguishers rated for energized electrical systems where electrical equipment is installed and operated.

CONTROL POINT: Design, Operations, Maintenance

(12) *Steam Pressure Washing*.
Description. Steam pressure washing of equipment may expose workers to thermal, burn or injection hazards, eye hazards from flying projectiles dislodged during pressure washing, slip hazards from wet surfaces, and noise hazards.

Control. Controls for steam pressure washing include:
- Use insulated gloves (e.g., silica fabric gloves) and keep all body parts away from the ejection point of the steam pressure discharge nozzle.
- Wear safety goggles and hearing protection.
- Wear slip-resistant boots.
- Drain water away from the decontamination operation into a tank or pit.
- Drain walking surfaces and keep free of standing liquids or mud.

CONTROL POINT: Construction, Operations, Maintenance

(13) *Blower Hazards*.
Description. High levels of noise may be generated by blowers and compressors and may result in hearing loss. Unguarded blowers and fans may entangle workers or their clothing, causing injury.

Control. Controls for blower noise and unguarded movement include:
- Control equipment noise with insulation, barriers, and proper equipment lubrication and maintenance.
- Use hearing protection around elevated noise levels.

- Use guards on all moving and rotating equipment.
- Inform workers that guards must be in place for equipment operation. Do not allow workers near unguarded machinery.

CONTROL POINT: Design, Operations

(14) *Muscle Injuries*.
Description. Manual lifting of heavy objects may expose workers to back, arm, and shoulder injuries.

Control. Controls for muscle injuries include:
- Do not require workers to lift heavy loads manually.
- Use proper lifting techniques including stretching, bending at the knees, and bringing the load close to the body prior to lifting (see EM 385-1-1, Section 14). Utilize more than one worker to manage loads.
- Use mechanical lifting equipment to lift or to move loads.

CONTROL POINT: Design, Construction, Operations, Maintenance

(15) *Emergency Wash Equipment*.
Description. Emergency shower/eye wash equipment required per 29 CFR 1910.151 is not always provided with adequate floor drains, thereby creating potential electrical hazards and walking surface hazards during required testing and use.

Control. A control for emergency wash equipment includes:
- See American National Standards Institute ANSI Z 358.1 – 1998: "Emergency Eyewash and Shower Equipment" for design requirements.
- Equip showers/eye wash equipment with accompanying functional drains to isolate and collect the shower/eye washwater from unprotected electrical equipment and walking surfaces that, when wet, create slipping and electrical hazards.

(16) *Design Field Activities*.
Description. Design field activities associated with subsequent construction may include surveying, biological surveys, soil gas surveys, geophysical surveys, trenching, drilling, stockpiling, contaminated groundwater sampling, and other activities. Each of these field activities may expose the survey personnel to physical, chemical, radiological, and biological hazards.

Control. Controls for hazards resulting from design field activities include
- Prepare an activity hazard analysis for design field survey activities. EM 385-1-1, Section 1, provides guidance on developing an activity hazard analysis.
- Train workers in hazards identified.

CONTROL POINT: Design

b. Chemical Hazards.

(1) *Liquid Waste Materials*.
Description. Piping systems may leak from over-pressurization and spray workers with liquid waste materials. As a result, workers may be exposed to the liquid waste through inhalation, ingestion or dermal contact.

Control. Controls for liquid waste materials include:
- Conduct regular system inspections, testing, and maintenance to prevent or minimize leaks and resulting exposures.
- Install hazard-warning alarms to alert workers of vessel over-pressurization and potential chemical hazards.
- Train the workers in the unique exposure hazards associated with the waste streams and in the controls to implement to prevent harmful exposures.

CONTROL POINT: Design, Operations, Maintenance

(2) *Contaminants (Well Installation).*
Description. During well installation, workers may be exposed to contaminants, such as VOCs, dusts, and metals in soil and development water through the inhalation/ingestion/dermal contact routes.

Control. Controls for contaminants include:
- Apply water or an amended water solution to the area during well installation to help control the generation of airborne dusts, particulates, and VOCs.
- Use respiratory protection including approved filters/cartridges such as N, R or P100 particulate air filters, OV cartridges for vapors, or combination filter/cartridges for dual protection.
- Analyze work tasks and potential for chemical exposure to determine the correct personal protection equipment (PPE) or respirator cartridges. The analysis should include a chemical waste profile to help ensure that the PPE specified will be appropriate for the respective chemical hazards.

CONTROL POINT: Construction, Operations, Maintenance

(3) *Chemical Exposure Via Dual-Phase Extraction.*
Description. During operation of a dual-phase extraction system, workers may be exposed to chemical materials, such as hydrogen sulfide, VOCs, and intermediate byproducts.

Control. Controls for chemical exposure include:
- Wear respiratory protection to control inhalation exposures based on an analysis of the type of respirator required before issuance.

- Include a chemical profile on the waste materials to ensure that the specified respirator and filter/cartridge or supplied air will be appropriate.

CONTROL POINT: Design, Operations, Maintenance

c. Radiological Hazards.

(1) *Radioactive Materials*.
Description. In some geological settings, workers may be exposed to naturally occurring radon gas. Radon gas and radon progeny do not present a significant external hazard. While radon progeny may present an internal hazard, the quantities of radon progeny normally present would not pose a significant exposure hazard.

Control. Controls for radioactive materials include:
- Check operation of emission control technologies to limit exposure.
- Consult a qualified health physicist for proper guidance if excessive levels are suspected or encountered.

CONTROL POINT: Design, Operations, Maintenance

(2) *Radioactive Devices*
Description. Fire and smoke detection devices, fluid level devices, and other process monitors and switches may contain radioactive devices potentially exposing workers through lack of identification or mishandling.

Control. Controls for inadvertent handling or exposure to radioactive devices include:
- Workers should be prevented from and warned against tampering with the devices.
- The location of the devices should be recorded so as to safely retrieve and dispose devices in case of a system failure and equipment replacement.

CONTROL POINT: Design, Operations and Maintenance

d. Biological Hazards.

Opportunistic Insects and Animals.
Description. For all sites, but especially in cooler climates, opportunistic insects or animals can nest in and around warm process equipment. Vermin, insect, and arthropod control measures should be considered in any design.

Control. Control of opportunistic insect and animals include:
- Electrical cabinets and other infrequently opened enclosures should be opened carefully and checked for black widow and brown recluse spiders, and evi-

dence of rodents. As rodents can cause damage to electrical cables, all wiring should be inspected regularly.

- Ensure all storage is off the ground, palleted, and kept dry. Damp areas attract scorpions, rodents, and the snakes that eat them.
- Design ceiling corners and other high areas to discourage nesting by swallows, pigeons, and other birds. Birds are carriers of diseases, especially in their droppings, which can foul cranes and process equipment.

CONTROL POINT: Design, Operations and Maintenance